



Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at <http://about.jstor.org/participate-jstor/individuals/early-journal-content>.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE SEX RATIO IN HYBRID RATS.

HELEN DEAN KING,

THE WISTAR INSTITUTE OF ANATOMY AND BIOLOGY.

It has frequently been stated that the sex ratio in mammals can be altered by hybridizing, although there are but few series of observations that give support to such a view. Buffon (1709-1788) seems to have been one of the first to note the apparent excess of males among hybrid offspring; but as his records comprise only a comparatively small number of cases they cannot be considered to afford conclusive evidence that hybridizing changes the normal proportion of the sexes.

In recent times little attention has been paid to the question of the sex ratio in hybrid offspring. Davenport ('06) ascertained the sex of 377 out of a total of 950 hybrid fowls obtained in an extensive series of investigations on inheritance in poultry, and found 204 males and 173 females. Taking the sex ratio for any given lot of individuals as the number of males to each 100 females, it is found that among these hybrids the sexes exist in the ratio of 117.91 males to 100 females. This sex ratio seems to indicate that there is a pronounced excess of males among hybrid fowls, yet Davenport states that the proportion of the sexes in hybrids is normal, and that "the exceptions to the law of equality of sexes in hybrid offspring are individual and not of general significance." Davenport attributes the excess of males among his 377 hybrid fowls to a difference in the death rate of the two sexes, yet he gives no figures to show that among young poultry more females die than do males. Human statistics, as well as the records I have been collecting for the albino rat, indicate that mortality is greater among young males than among young females. Davenport's conclusion does not appear to apply to hybrid birds in general, as Guyer ('03, '09) found a great excess of males among hybrid pigeons, and the data which he has collected regarding the sex of other hybrid birds show a very much greater number of males than of females in practically every case.

In order to study the color combinations in hybrid mice von Guaita ('98, '00) crossed albino mice with Japanese waltzing mice and inbred their descendants through six generations. In his various tables von Guaita gives the sex of the great majority of the hybrid offspring obtained in each generation, yet he makes no comment whatever on the relative proportion of the sexes in these individuals. For the purpose of comparing the sex ratio in hybrid mice with that in hybrid rats, von Guaita's sex records have been collected and the sex ratios calculated for the individuals in each generation. The data thus obtained are shown in the following table.

TABLE I.
SEX DATA FOR HYBRID MICE (VON GUAITA).

Generation.	No. Hybrids.	Sex Unknown.	Males.	Females.	No. Males to 100 Females.
F ₁	31	3	16	12	133.33
F ₂	45	0	21	24	87.50
F ₃	77	0	39	38	102.63
F ₄	134	21	60	53	113.20
F ₅	95	9	48	38	126.31
F ₆	25	18	5	2	
	407	51	189	167	113.17

According to these records von Guaita obtained a total of 407 hybrid mice; but he gives the sex of only 356 individuals, of which 189 were males and 167 were females. In this lot of hybrids, therefore, there are 113.17 males to 100 females. This sex ratio is undoubtedly higher than that which is normal for either of the two species with which the experiments began. Schultze ('03) found a nearly equal proportion of the sexes in over 1,000 albino mice that had been bred under different environmental conditions; a similar relation between the sexes existed in the 135 waltzing mice bred by Yerkes ('07).

Raymond and Maud D. Pearl ('08) have tabulated over two hundred thousand records of legitimate births occurring in the city of Buénos Ayres during the years 1896-1905 inclusive, in order to ascertain whether there is a tendency towards an excessive production of offspring of one sex in cross as compared with pure matings. Their tables show that in pure matings, either among Argentine, Italian or Spanish stock, the number of males

to each 100 females ranges from 100.77 to 105.55 in various cases. Among these races, therefore, the same relation of the sexes exist as is normally found when any large number of human births are examined. When the parents were of different racial stock there is a marked increase in the relative number of males; the sex ratio showing from 105.72 to 106.74 males for each 100 females. The general conclusion reached by these investigators is that "there is a definite tendency towards an excessive production of male offspring in cross as compared with pure matings in the data considered. Further, it appears that this tendency is uniformly exhibited in all the matings."

The records given above comprise all the sex data for considerable numbers of hybrid offspring that I have been able to find. All of these records are in complete accord, since in each case there is an excess of males that is much greater than that which is probably normal for the parent stock.

For several years past Dr. S. Hatai, of the Wistar Institute, has been crossing the wild Norway rat (*Mus norvegicus*) with the albino rat (*Mus norvegicus albinus*) and breeding their descendants, in order to obtain material for a study of the central nervous system in hybrid rats. The records for the many hybrid offspring that have been examined include the sex data, and Dr. Hatai has generously offered me the use of these records for the study of the sex ratios that is given in the present paper. As far as I am aware, there are no published statistics regarding the proportion of the sexes among hybrid rats, although three investigators, von Fischer ('74), Crampe ('84) and Bos ('94), have carried on extensive hybridizing and inbreeding experiments with these animals.

Cuénot ('99) examined 30 litters of young albino rats containing a total of 255 individuals, and found among them a sex ratio of 105.6 males to 100 females. Records which I have made of the sex of 452 young albino rats belonging to 80 litters give a sex ratio of 107.33 males to 100 females. The sex ratio in the albino rat, therefore, agrees with that for man and various other mammals, since the number of the males is slightly greater than that of the females.

No statistics have as yet been collected regarding the normal

proportion of the sexes among wild Norway rats. Judging from the sex ratio found in general among the mammals, it is very probable that there is approximately an equality of the sexes in the wild Norway rat as in the albino rat. In the total of 607 albino rats examined by Cuénot and by myself there was found a sex ratio of 106.46 males to 100 females. This sex ratio is considered, throughout this paper, to express the probable normal relation between the sexes in the wild rat as well as in the albino rat.

Four series of experiments were made in which albino rats were crossed with wild Norway rats. Records are available for a total of 163 individuals belonging to the F_1 generation, of which 89 were males and 74 were females. Among these hybrids, therefore, there is a sex ratio of 120.26 males to 100 females. Although this sex ratio is much higher than that which is probably normal for either of the parent species, it is not as high as that found in von Guaita's first generation of hybrid mice where the sexes existed in the ratio of 133.33 males to 100 females (Table I.).

All of the hybrid rats belonging to the F_1 generation for which records were made were at least five months old when they were killed and examined; the few individuals that died before reaching maturity were not included in the records. It cannot be determined with any degree of certainty, therefore, to what proportion of the entire number of offspring belonging to the F_1 generation the above sex ratio applies. Very few of the young rats died, as far as is known, and there is no reason to suppose that the mortality was greater among the young females than among the young males. It seems probable, therefore, that the sex ratio in the 163 individuals for which data are available is fairly representative for the entire number of offspring produced in the course of the various experiments to which they belonged.

Two of the four series of experiments mentioned above were extended by mating various individuals belonging to the first generation of hybrids. In pairing these animals no attention was paid to their blood relationship, and undoubtedly nearly related individuals were mated in many cases.

In one series of experiments only a very small number of individuals belonging to the second generation of hybrids died

before reaching maturity, and the 114 rats for which records are at hand form a very great majority of all of the offspring produced. Of these individuals 61 were males and 53 were females; this gives a sex ratio of 115.09 males to 100 females.

In the other series of experiments the majority of the individuals belonging to the F_2 generation died while immature, and records were made for only 27 individuals. Since twice as many females as males reached maturity, it is evident that in this instance either the mortality was much greater among the young males than among the young females or that there was a very unequal distribution of the sexes in the newborn rats.

Individuals from only one lot of hybrids belonging to the second generation were mated. The animals were paired according to color, their possible blood relationship being entirely disregarded. Dr. Hatai found, as have other investigators who have bred hybrid rodents, that there is increasing infertility among individuals belonging to succeeding generations of hybrids. The total number of hybrid offspring belonging to the F_3 generation was relatively small: many of the rats were stunted in their development, and the majority of them died before reaching maturity. Since records are available for only 23 of these individuals the sex ratio among them can give no idea of the probable ratio in a large number of hybrids belonging to the third generation.

Since in mating individuals belonging to the first and to the second generation of hybrids no attention was paid to their blood relationship, it is very probable that in some cases closely related individuals were paired. There is the possibility, therefore, that inbreeding might have had some influence on the sex of the descendants. According to Düsing ('84), a noticeable increase in the number of male offspring is produced by inbreeding, in man as well as in various mammals. Inbreeding could have had little, if any, influence on the sex ratios in these various lots of hybrid rats. The sex ratio found among the 114 hybrids of the F_2 generation which comprise practically all of the offspring produced in the series of experiments to which they belonged, is somewhat less than that found among the offspring produced by crossing pure stock (Table II.). The data for

the other individuals belonging to the F_2 generation, as well as those for the hybrids of the F_3 generation, show an excess of females. These latter records cannot be considered to furnish evidence against Düsing's theory, since they include such a very small number of individuals. There seem to be no records, except those given by Düsing, that show that inbreeding alone produces a relatively greater number of male than of female offspring. Schultze was unable to detect any change in the sex ratio of albino mice that had been inbred for four generations, and I have found no unusual excess of males among some 500 individuals belonging to five generations of inbred albino rats.

Records are available for 121 other hybrid rats, most of which were the offspring of reciprocal crosses. These individuals all belonged to the F_2 or to the F_3 generation of hybrids; and among them were 72 males and 49 females. These hybrids were selected, because of their size and condition, from a considerable number of individuals for which no records were made. There was, therefore, undoubtedly an unconscious selection of males in choosing the rats to be examined, since the adult male rat is considerably larger and heavier than the female. The data for these various lots of selected individuals have been combined in one group, since they are of value only because they show the sex of a considerable number of hybrids.

The following table gives a summary of the sex records for all of the hybrid rats recorded.

TABLE II.
SEX DATA FOR HYBRID RATS.

Generation.	No. Hybrids.	Males.	Females.	No. Males to 100 Females.
F_1	163	89	74	120.26
F_2	114	61	53	115.09
F_2	27	9	18	50.00
F_2 and F_3	121	72	49	146.93
	425	231	194	119.07

In the total of 425 hybrid rats for which records were made, 231 were males and 194 were females. Among these individuals, therefore, there is found a sex ratio which is considerably higher than that which is probably normal for either the albino or the wild Norway rat, since there are 119.09 males to 100 females.

If from the above table we omit the records for the 27 individuals belonging to the F_2 generation of hybrids which formed only a very small percentage of the total number of offspring produced in the experiment to which they belonged and also the records for the selected individuals belonging to the F_2 and to the F_3 generation, there remain the data for 277 individuals which comprise the very great majority of the hybrid offspring obtained in several series of experiments. It would seem as if the sex ratio in these individuals might justly be taken to represent the probable sex ratio in any large lot of hybrid rats. Of these individuals 150 were males and 127 were females; this gives a sex ratio of 118.11 males to 100 females. This sex ratio is but very little lower than that found in the total number of hybrids for which records are at hand, and it is not very much higher than that in the 356 hybrid mice bred by von Guaita (Table I.).

The excess of males among these hybrid rats is seemingly beyond the limits of normal variation in the proportion of the sexes in the pure stock, and it is too uniform in the various series of experiments to be attributed to chance. It appears, therefore, that hybridizing alters the sex ratio by producing a marked increase in the relative proportion of males. This conclusion is in essential agreement with that reached by Buffon, by R. and M. Pearl and by Guyer.

Guyer ('09) has offered an explanation for the excess of males among hybrid offspring which accords with the theory, advocated by a number of investigators, that sex is determined in the ovary chiefly by nutritive conditions. Guyer suggests that in the zygote produced by cross fertilization there would probably be "more or less default in the metabolic processes because of the incompatibilities which must necessarily exist between two germ-plasms so dissimilar." An interference with the metabolic processes would naturally retard the constructive phases of metabolism in the fertilized ovum, and therefore tend to the production of relatively more males, since the theory assumes that females are produced only when the conditions are most favorable for constructive metabolism.

To explain the sex ratio in hybrids according to the current

hypothesis that the male is the sex-determining factor seems to necessitate the further assumption that fertilization is selective when individuals belonging to different races are crossed, the egg offering greater resistance to the entrance of a spermatozoan that is female-producing than to one that is male-producing. There is little evidence, as yet, that fertilization is ever selective. The probability of its occurrence as a normal phenomenon has recently been advocated by Heape ('09), although Wilson ('10) considers it "so improbable as almost to invalidate any interpretation into which it enters."

Guyer ('03) has shown that there is considerable amount of degeneration in the testes of many hybrid pigeons; abnormal mitoses and misshapen spermatozoa being of frequent occurrence. Other observers have stated that the gonads in hybrids are more or less defective; but none of them have made a histological investigation in order to ascertain what structural changes have been produced. Guýer's observations strongly suggest that results of value may be obtained by a study of the gonads in other hybrids. Material is being collected for an investigation of the gonads in hybrid rats, in the hope that it will at least give some clue to the cause for the increased sterility in succeeding generations of hybrids, even if it affords no evidence that will enable one to offer a satisfactory explanation for the altered sex ratio in hybrid forms.

LITERATURE CITED.

Bos, Ritzema.

- '94 Untersuchungen ueber die Folge der Zucht in engster Blutverwandschaft. Biol. Centralbl., Bd. XIV.

Crampe, Dr.

- '84 Zucht-Versuche mit zahmen Wanderratten. II., Resultate der Kreuzung der zahmen Ratten mit wilden. Landwirthschaft. Jahrbücher, Bd. XIII.

Cuénot, L.

- '99 Sur la determination du sexe chez les animaux. Bull. sci. de la France et de la Belgique, T. 32.

Davenport, C. B.

- '06 Inheritance in Poultry. Pub. Carnegie Inst., No. 52.

Düsing, K.

- '84 Die Regulierung des Geschlechtsverhältnisse bei den Vermehrung der Menschen, Tiere, und Pflanzen. Jen. Zeitschr. Naturwiss., Bd. XVII.

von Fischer, J.

- '74 Beobachtungen ueber Kreuzungen verschiedener Farbenspielarten innerhalb einer Species. Zoöl. Garten, Bd. XV.

von Guaita, G.

'98 Versuche mit Kreuzungen von verschiedenen Rassen der Hausmaus. Ber. Naturforsch. Gesellsch. zu Freiburg, Bd. X.

'00 Zweite Mittheilung ueber Versuche mit Kreuzungen von verschiedenen Hausmausrassen. Ber. Naturforsch. Gesellsch. zu Freiburg, Bd. XII.

Guyer, M. F.

'03 Spermatogenesis of Normal and of Hybrid Pigeons. Bull. Univ. Cincinnati, No. 22.

'09 On the Sex of Hybrid Birds. Biol. Bull., Vol. XVI.

Heape, W.

'09 The Proportion of the Sexes Produced by White and Coloured Peoples in Cuba. Phil. Trans. Royal Soc., London, Vol. 200.

Pearl, M. D. and R.

'08 On the Relation of Race Crossing to Sex Ratio. Biol. Bull., Vol. XV.

Schultze, O.

'03 Zur Frage von den Geschlechtsbildenden Ursachen. Arch. mikr. Anat., Bd. LXIII.

Wilson, E. B.

'10 Selective Fertilization and the Relation of the Chromosomes to Sex-Production. Science, Vol. XXXII.

Yerkes, R. M.

'07 The Dancing Mouse. The Macmillan Co., New York City.